CHEMICAL ENGINEERING STUDENTS: A DISTINCT GROUP AMONG ENGINEERS

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In traditional analyses of students' career choice, students in engineering majors are often treated as a monolithic population rather than belonging to a constellation of related disciplines. A few studies have documented different types of students and cultures within engineering disciplines,[1–3] but there is little discussion about how students' attitudes and perceptions of engineering disciplines affect their choice of major upon entrance into college and the characterization of these students. Studies that have been published have compared personality types through tests like Myers-Briggs, which have validity problems, especially due to the lack of relevant context.[4] Additionally, much of this work was conducted more than 30 years ago, and there is little current work on articulating students and cultures of different engineering disciplines. One study that does illustrate the differences between engineering groups examined the different attitudes between industrial engineering students and more traditional mechanical and electrical students at a single institution.[5] The conclusions from this study provide motivation to further explore this under-researched area: "Instead of examining the characteristics of persons gravitating toward engineering, we should inquire into what types of persons select which types of engineering."[5] Another study examined the differences between chemical engineers and other engineering students, science students, and non-science students. The data from this study were limited to transcript information from the Southeastern University and College Coalition for Engineering Education (SUCCEED). The authors did find differences in chemical engineering students with higher SAT Math and Verbal scores, higher high school GPAs, longer time to graduation, higher cumulative college GPAs, fewer changes in declared major, and more semester hours than other students.[6] Because of its design, however, this study did not explore students' career interests and attitudes, which is the focus of our study. Further study of students' interests and attitudes about engineering disciplines is vital to the recruitment and retention of engineering students.

It has been shown that students will develop a strong attachment to their chosen major when the perceived identity of a practitioner agrees with a student's self-defined identity.[7–12] Additionally, students who are more familiar with specific engineering disciplines express a greater confidence in their choice of major.[13] These findings have important implications for how students are recruited into particular programs as well

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as how these students are instructed. With little literature on the differences between students who choose the spectrum of engineering disciplines, there is a missed opportunity to improve the recruitment, retention, and teaching practices for the students who enter chemical engineering classrooms, as well as other engineering majors.

Since high school students have not yet been fully exposed to science practice, let alone engineering practice, the choice of an engineering discipline upon entrance to college is only a partly informed decision. Many students enter college knowing they want to pursue engineering with particular career outcomes in mind, but they do not know which engineering discipline fits those career aspirations. Additionally, the coursework to prepare for a specific STEM career is often undifferentiated in high school. Some studies have attempted to classify different types of engineers by their career roles of research, development, production, and sales through using students' Strong Vocational Interest Blank (SVIB) scores. [14] These roles in industry are outdated and do not directly address the question of student attitudes and interest upon entrance into college, but these findings do add to the body of evidence that there are differences in engineers' specific interests and, more importantly, a specialization within the designation of a specific engineering career choice (*e.g.*, chemical, mechanical, electrical, etc.). Students just entering college may not be prepared to make a specialty choice in engineering. Instead, students choose an engineering discipline based on the perceived fit with their intentions and several irrational factors.[13] These findings add to the motivation to explore the underlying differences in students who choose different engineering disciplines.

Performance in math and science are not the primary reason that students either leave engineering studies or do not enter them in the first place.[15,16] Students reported that a loss of interest in their original major, pedagogical and curricular issues, disenchantment with perceived future careers, inadequate advising, lost confidence due to low grades or poor preparation, and—for females—covert or overt gender bias within the discipline, caused them to leave their originally declared major. In general, gaps between students' expectations and the perceived "fit" of a major result in students leaving. In *Talking About Leaving*, 10.5 percent of students initially declaring an engineering discipline as a major resettled within engineering, while 51.4 percent remained in the originally declared major, with the remaining group of students (38.1 percent), leaving engineering altogether.[15] A recent study of students switching from other engineering majors into industrial engineering found that the same pushes highlighted by Seymour and Hewitt continue to affect current engineering students.[16] From transcript databases, research has shown that engineering as a group does have one of the highest rates of persistence in STEM and the lowest rate of inward migration. Engineering students are also more likely to graduate in their declared major.[17] Additionally, testimony before the Subcommittee on Research of the Committee on Science for the U.S. House of Representatives in 2006 indicated that little, if anything, has changed since Seymour and Hewitt's findings almost 10 years prior. Current numbers show that 50 to 60 percent of students initially declaring a major in STEM eventually leave those studies. In view of the current situation in STEM attrition, the President's Council of Advisors in Science and Technology (PCAST) recently called for 1 million new STEM graduates over the next 10 years.[18] One way to address the need for more STEM graduates is through understanding which types of students choose engineering and how to more effectively recruit them upon entrance into college.

Understanding what factors (beliefs, attitudes, and goals) lead students to choose specific engineering disciplines can help address the need for new STEM graduates. By more thoroughly understanding students in chemical engineering departments, chemical engineering educators can better address their particular interests and needs. If, as expected, these students are different from non-engineering students, but are also different from their peers in other engineering disciplines, departments will reap many benefits from an improved understanding of their students.

In this paper, an exploration was conducted of pre-college factors (including academic backgrounds, classroom experiences, out-of-class experiences, attitudes, family influences, and demographic backgrounds) that impact students' chemical engineering career intentions, as measured by their self-identified likelihood of choosing a career in a specific engineering discipline. The results illustrate the specific differences in chemical engineering students identified in a nationally representative sample of college freshmen, and provide emphasis for the statement that "engineers should not be lumped together into a single category."[14]

METHODS

The data used in this study were drawn from a subsection of the Sustainability and Gender in Engineering (SaGE) survey (<http://www.clemson.edu/~gpotvin/SaGE.pdf>), a large- scale study of students in introductory English courses enrolled in colleges across the United States (NSF GSE 1036617). This methodology uses a cross-sectional approach relying on the natural variation in students' experiences and backgrounds across the United States. The SaGE project used a representative, stratified, random sample taken from a comprehensive list of four-year and two- year institutions. A list of all colleges and universities in the United States was obtained from the National Center for Education Statistics (NCES) and was divided by institution type (two-year or four-year) and by institution size (small, medium, or large) into six lists. Each list was randomized and then recruiters contacted schools on each list. The stratification accounted

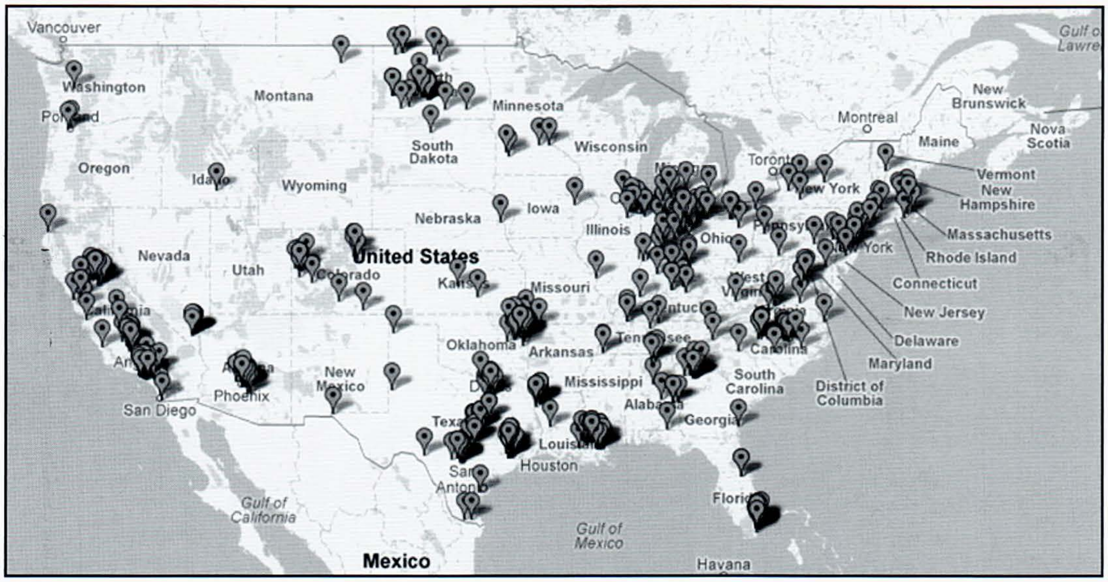

Figure 1. *Engineering students' hometowns in the contiguous United States created with BatchGeo.*[21]

for the size of the institution and prevented over-sampling of the smaller, but numerous, liberal arts colleges. In total, 50 schools agreed to participate in the survey. The survey was administered in required freshman English courses to capture a sample representative of both STEM and non-STEM majors. In all, 6,772 students completed the survey during the administration period in the Fall of 2011. The survey instrument focused on student backgrounds, pedagogical factors in physical science classrooms, classroom achievement, and student attitudes toward STEM and sustainability. Sustainability is most commonly and broadly defined as meeting the "needs of the present without compromising the ability of future generations to meet their own needs."[19] The intent of the study was to focus on factors that increased enrollment in engineering majors and to explore the connections between engineering and sustainability-related topics in students' experiences.

Using this retrospective cohort methodology, substantial natural variability in students' background and prior experiences can be captured. Students reported that they came from homes in at least 2,533 different ZIP codes across the United States. A map of the engineering students' home ZIP codes in the contiguous United States can be seen in Figure 1. This map is included to illustrate the geographic representativeness of the population which is reflective of the population of the United States.[20] International students are included in the study as a part of the cross- sectional sample gathered from the 50 institutions surveyed. Of the total student population that completed the demographic portion of the survey, 54.7% were female. Of the 814 students who indicated the choice of any intended engineering career, 19.8% of respondents were female.

The final version of the survey included 47 questions about student career goals, high school science experiences, earlier math, and science enrollment and achievement (including types of courses taken, the level of courses, the year courses were taken in high school, final grades, and AP test scores), student attitudes about sustainability, and demographic information. These questions consist of primarily Likert, Likert-type, multiple-choice, and categorical items.

Multiple aspects of validity and reliability of the instrument were assessed. An open-ended hypothesis-generation survey was collected from 82 first-year engineering and 41 non-engineering students, as well as 83 high school science teachers (recruited via the listserv of the National Science Teachers' Association). Lending to content validity, these hypotheses were included in the survey. Questions were further refined based on feedback from assessors and the results of pilot testing in a first-year freshman engineering course. In-person pilots of the survey and focus groups were conducted with first-year freshmen engineering students. Thus, each item of the survey was further examined for face and content validity.

One question used in this analysis asked students to "Please rate the current likelihood of your choosing a career in the following:". The various career options were "Mathematics," "Science/math teacher," "Environmental science," "Biology," "Chemistry," "Physics," "Bioengineering," "Chemical engineering," "Materials engineering," "Civil engineering," "Industrial/systems engineering," "Mechanical engineering," "Environmental engineering," and "Electrical/computer engineering." Students were asked to rate the likelihood of choosing a career in each discipline on a Likert-type scale from 0 ("not at all likely") to 4 ("extremely likely"). In the current analysis, students that responded as "extremely likely" to choose a career in chemical engineering were grouped together, and all other students that responded "extremely likely" to choose at least one other engineering discipline were grouped together for a comparative analysis. The reason for this choice was to identify students with the most unambiguous intentions of majoring in chemical engineering on the one hand and all other engineering disciplines on the other.

TABLE 1
T-test outcomes for linearized variables.

Variable	ChE Students (Mean ± Std. Error) N=123	Other Engineering Students (Mean ± Std. Error) N=691	Level of Significance§ (*: p< 0.05, **: p< 0.01, ***: p<0.001)
Career goals: solving societal problems (scale: 0-not at all important; 4-very important)	**2.50 ± 0.02**	2.22 ± 0.27	*
Career goals: making use of my talents and abilities	**3.63 ± 0.01**	3.48 ± 0.14	*
Career goals: applying math and science	**3.20 ± 0.09**	2.80 ± 0.32	***
In biology asked questions, answered questions, or made comments (scale: 0-never; 4-daily)	**3.22 ± 0.08**	2.85 ± 0.30	***
In chemistry asked questions, answered questions, or made comments (scale: 0-never; 4-daily)	**3.39 ± 0.23**	2.74 ± 0.43	***
In physics asked questions, answered questions, or made comments (scale: 0-never; 4-daily)	**3.19 ± 0.04**	2.84 ± 0.33	*
Interest in understanding natural phenomena (scale: 0-not at all interested; 4-very interested)	**2.94 ± 0.09**	2.50 ± 0.36	**
Interest in understanding science in everyday life (scale: 0-not at all interested; 4-very interested)	**3.11 ± 0.12**	2.67 ± 0.34	***
Interest in explaining things with facts (scale: 0-not at all interested; 4-very interested)	**3.24 ± 0.08**	2.88 ± 0.29	***
Interest in telling others about science concepts (scale: 0-not at all interested; 4-very interested)	**3.04 ± 0.21**	2.39 ± 0.45	***
Interest in making scientific observations (scale: 0-not at all interested; 4-very interested)	**3.04 ± 0.12**	2.55 ± 0.38	***
Confidence in designing an experiment to answer a scientific question (scale: 0-not at all confident; 4-very confident)	**2.81 ± 0.06**	2.44 ± 0.32	**
Confidence in conducting an experiment on your own (scale: 0-not at all confident; 4-very confident)	**3.03 ± 0.10**	2.62 ± 0.32	***
Confidence in interpreting experimental results (scale: 0-not at all confident; 4-very confident)	**2.99 ± 0.10**	2.59 ± 0.32	***
Confidence in writing a lab report/scientific paper (scale: 0-not at all confident; 4-very confident)	**2.90 ± 0.18**	2.30 ± 0.43	***
Confidence in applying science knowledge to an assignment or test (scale: 0-not at all confident; 4-very confident)	**3.04 ± 0.09**	2.63 ± 0.33	***
Confidence in explaining a science topic to someone else (scale: 0-not at all confident; 4-very confident)	**3.24 ± 0.24**	2.58 ± 0.44	***
Confidence in getting good grades in science (scale: 0-not at all confident; 4-very confident)	**3.50 ± 0.17**	2.98 ± 0.36	***
Learning science will improve career prospects (scale: 0-strongly disagree; 4-strongly agree)	**3.45 ± 0.11**	3.04 ± 0.30	***
Science is helpful in my everyday life (scale: 0-strongly disagree; 4-strongly agree)	**3.23 ± 0.08**	2.87 ± 0.29	***
Science has helped me see opportunities for positive change (scale: 0-strongly disagree; 4-strongly agree)	**3.27 ± 0.13**	2.84 ± 0.32	***
Learning science has made me more critical in general (scale: 0-strongly disagree; 4-strongly agree)	**3.14 ± 0.08**	2.77 ± 0.30	**
I see myself as a physics person (scale: 0-strongly disagree; 4-strongly agree)	**2.74 ± 0.10**	2.25 ± 0.41	**
Chemistry topics are relevant to my life (scale: 0-never; 4-daily)	**2.69 ± 0.14**	2.15 ± 0.41	***
Highest Chemistry Course Taken (scale: 0-none; 1-one course; 2-two courses)	**0.84 ± 0.01**	0.65 ± 0.18	*
Last chemistry grade (scale: GPA)	**3.62 ± 0.05**	3.29 ± 0.28	**

§ *The level of statistical significance is coded in the final column: * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001.*

According to the classification outlined above, 123 students in the sample were categorized as chemical engineering students (29.3% of which were female) and 691 students were categorized as "other" engineering students (18.1% of which were female). The chemical engineering students were composed of 72% freshman, 21% sophomores, and 7% upperclassman. Similarly, the "other" engineering students were composed of 73% freshman, 20% sophomores, and 7% upperclassman.

For the questions with linear responses, Welch's t-test was used to compare the mean responses of chemical engineering with other engineering students.[22] A chi-square test was used for dichotomous variables to assess whether there is a statistically significant difference in the responses of the two groups.[23] For all tests performed in this analysis, the maximum probability of Type-I error (*e.g.*, a false positive result) that was permitted was 5%. Note that only survey items pertaining to student preparation, background, and attitudes were analyzed in this paper. All analyses were conducted using the statistical software system R.[24]

RESULTS

The results of the various t-test and chi-square tests are summarized in Tables 1 and 2. Only tests relating to the research question that were statistically significant are reported; in total, 26 linear and seven dichotomous variables showed significant differences.

For each variable in Table 1, the mean and standard error are given for both groups of students. The larger mean is listed in bold. Similarly, Table 2 gives the results from the chi-square tests. The percentages of each group answering affirmatively to each factor are listed, followed by the statistical significance. The higher percentage is listed in bold. Tests for related variables are grouped together in Table 1: first, career goals (in gray); second, science identity variables (in white); third, high school chemistry experiences (in gray). In Table 2 the questions are also grouped together: first, sustainability factors for career goals (in gray); second, family involvement (in white); third, type of high school (in gray).

As indicated in Tables 1 and 2, chemical engineering students show several substantial differences from students in other engineering disciplines. To understand the uniqueness of chemical engineering students and consider how to specifically design pedagogy for these students, it is instructive to consider the meaning of the related blocks of factors that were found to be significant.

In considering the demographic and prior educational experiences of chemical engineering students, there were several factors that were found to be not significantly different from other engineers including: SAT/ACT scores, high school physical science classroom experiences, family background, number of AP credits, and math and science preparation factors. This finding is perhaps not surprising since prior literature has shown that engineering students in general who persist are well prepared for their college courses.[15] The only overlap between the current work and the study by Zhang and colleagues is students' SAT scores and high school GPA. This earlier work found that chemical engineering students had higher SAT scores and GPAs than other engineering students.[6] Some reasons for the differences in these findings are that the transcript data collected by Zhang and colleagues range from 1988 to 2003, while the data in this study were collected from students enrolled in the Fall of 2011. In 2005, between these studies, the SAT assessment changed significantly.[25] In addition, Zhang and colleagues' sample is limited to Southeastern schools with several listed as research universities with "high" or "very high" research activity, which may have limited the earlier sample to exceptional engineering students.[26] There are a few indicators that students in chemical engineering come from a somewhat higher socioeconomic background than other engineering majors: students are more likely to come from a foreign high school ($p<0.05$) and these students' families are more likely to have arranged a tutor in math or science in the past ($p<0.01$). Many of the high school classroom practices and student attitudes were not found to be different, as well as a number of variables related to students' high school science course length, class sizes, frequency of meetings and activities. Similarly, students were questioned

TABLE 2
Chi-square test outcomes for dichotomous variables.

Variable	Percent of ChE Students Indicating (N=123)	Percent of Other Engineering Students Indicating (N=691)	Level of Significance (*: p < 0.05, **: p < 0.01, ***: p<0.001)
Want to address energy in career	**60%**	47%	*
Want to address disease in career	**39%**	18%	***
Want to address climate change in career	**20%**	11%	*
Want to address water supply in career	**34%**	19%	***
Science was a diversion or hobby in my family	**37%**	26%	*
My family arranged for tutoring in science	**20%**	10%	**
Attended a foreign high school	**10%**	4%	*

about their out-of-school science activities such as hobbies, exposure to science-related media, and possible engineering influences. These results suggest that, while such factors may have a significant impact on the recruitment of students into engineering, no differential effects could be found for chemical engineering majors.

Students' prior experiences in chemistry courses differed between chemical engineers and other engineering majors. Chemical engineering students more often take a higher-level chemistry course ($p<0.05$) and have higher chemistry grades than other engineering students ($p<0.01$). Additionally, these students report higher levels of engagement with the material, positive interactions with other students, and highly rated chemistry teachers. Student engagement was measured by how often the student asked questions, answered questions, or made comments in his/her classes ($p<0.001$) as well as measuring how interested the student was in his/her high school chemistry classes ($p<0.01$). Students identified chemistry topics as more relevant to their everyday lives ($p<0.001$).

Chemical engineers listed some career outcome expectations that were different from other engineering students. A surprising finding was that chemical engineers reported a stronger desire to apply math and science in their future career over other engineers ($p<0.001$). Chemical engineers also reported a stronger interest in solving societal problems ($p<0.05$) and making use of their talents and abilities ($p<0.05$). Some specific ideas related to sustainability were also highlighted as concerns that chemical engineers specifically hoped to address in their careers including: energy ($p<0.05$), disease ($p<0.001$), climate change ($p<0.05$), and water supply ($p<0.001$).

Chemical engineering students showed a strong interest in science and understanding the world around them. They indicated higher scores on their interest in understanding natural phenomena ($p<0.01$), understanding science and everyday life ($p<0.001$), explaining things with facts ($p<0.001$), telling others about science concepts ($p<0.001$), and making scientific observations ($p<0.001$). Another set of questions measures students' confidence in their scientific and mathematical abilities. Chemical engineers reported significantly higher differences on their abilities to design an experiment to answer a scientific question ($p<0.01$), conduct an experiment on their own ($p<0.001$), interpret experimental results ($p<0.001$), write a lab report or scientific paper ($p<0.001$), apply science knowledge to an assignment or test ($p<0.001$), explain a science topic to someone else ($p<0.001$), and get good grades in science ($p<0.001$).

Identity

To clarify the questions addressing students' interest and confidence discussed above, a composite measure of "science identity" was constructed using several of these items. As a construct, identity has been conceptualized as inherently related to individuals' self-beliefs.[10] In this study the particular context of interest is that of an engineering discipline. The importance of understanding identity is highlighted by Brickhouse and colleagues: If more students are to enter science and engineering, they need to see themselves as the "kind of people who would want to understand the world scientifically."[11] The construct of identity is based on four measurable dimensions of students' beliefs about their performance, competence, recognition by others, and interest.[8] These four dimensions richly capture an individual's self-perceptions and can be used to study the development of an engineering identity specifically in relation to critical events in students' experiences, their perceptions of the world around them, and the development of agency (*i.e.*, beliefs about the ability to act and enact change in one's world) in their lives and careers. The study of identity has proven useful in understanding college persistence.[12] This framework for measuring identity has been previously used in large-scale studies of physics and mathematics.[8]

Of the four sub-constructs of identity, the recognition component consists of beliefs about external recognition by parents, teachers, other students, etc., of an individual person as a good science student. Interest in the subject material also plays a key role in the choice of an engineering major. In this analysis, the questions used to construct an identity composite are the interest and confidence questions in Table 1 (which include students' perceptions of their performance and competence together) and the questions about family recognition and involvement in Table 2, all of which were found to be highly correlated with one another for each of the four sub-constructs measured.[8] These questions were averaged for each of the sub-constructs of identity (interest, recognition, performance, and competence) and used to compare chemical engineering students with other engineering students. Performing a t-test to compare chemical engineers and other engineers on this composite shows that the former have a higher overall science identity than the latter ($p<0.001$). Thus, chemical engineers appear to be responsive in ways that are somewhat more akin to traditional physical scientists than other engineers.

DISCUSSION

To a certain extent, these findings agree with prior work investigating the differences between engineering disciplines. Namely, this analysis found that there are, in fact, notable differences between chemical engineering undergraduates in career aspirations, perceived identities, and approaches to learning. This work is a step towards clarifying some of the differences between students who choose chemical engineering in college and others.

In utilizing a cross-sectional study design, the data gathered have some strengths: large statistical power, national representativeness in the sample, and the ability to test hypotheses surrounding events that were introduced to students naturally rather than through an intervention. This study design also has certain weaknesses, notably including the inability to draw causal conclusions. Rather, results are correlational in nature. The results do indicate substantial correlations between student responses and students' choice of major, but further work is necessary to indicate a causal direction to these relationships. For example, students may see chemistry topics as relevant to their everyday lives because of their choice of chemical engineering as a major, or they may choose chemical engineering because of their prior view of chemistry as relevant to their lives.

Students' experiences in their high school chemistry classrooms tell us how students engaged in chemistry classes may develop a particular connection to the material and see a future in chemical engineering. Chemical engineering students usually take a second course in chemistry and do better than other future engineering students. The particular reasons why these students choose chemical engineering over chemistry are not yet clear, but may be rooted in better or more extensive math preparation, a stronger connection to hands-on applications of science, or other factors. The differences between chemists and chemical engineers upon entrance into college are an interesting topic that will be explored in the future.

A stronger interest in solving societal problems and addressing issues such as disease may point to chemical engineering students being interested in industries such as pharmaceuticals or possibly going on to a career in medicine. Connecting curriculum to current issues facing our global community may help to harness chemical engineering students' concerns related to the sustainability-related issues that were highlighted in this analysis. The inclusion of emerging fields such as nanotechnology and biomolecular engineering within traditional chemical engineering instruction is also suggested by these findings; these topics have direct connections to future solutions in human health and environmental applications. Also, in engineering, the perceived lack of a connection to societal problems is a substantial barrier to women entering the field,[27] and the subject of sustainability can overcome this barrier by explicitly connecting engineers' contributions to solving problems such as resource depletion, catastrophic climate destabilization, and social inequity. As STEM educators move toward the recruitment and education of 1 million extra STEM graduates in the next 10 years, attracting more women and students from other traditionally marginalized groups into engineering is vital.[18] By reducing some of the barriers to women relating to engineering through curricular choices, some of these hindrances may be addressed by our current chemical engineering faculty.

Perhaps unsurprisingly, chemical engineers have more positive experiences in their high school chemistry courses than other engineering students. Such findings could be expected due to typical college admissions requirements and the motivations of students who traditionally intend to enter chemical engineering. These positive experiences may partially explain why students have a significantly stronger science identity than their peers. Zhang and colleagues found that chemical engineering students transferred more frequently to physical science majors than other engineering students and that students leaving physical science and entering engineering chose chemical engineering over other engineering disciplines more frequently.[6] These results triangulate the current paper's finding of a higher science identity among chemical engineering students. These students may also have a stronger connection with chemistry as it relates to their everyday lives and see chemical engineering as a way to positively affect the world around them, desires to solve societal problems, and apply mathematics and science in their careers. A strong science identity coupled with the desire to apply math and science also has implications for educators' curricular choices. Traditionally, students spend much of their time in the first two years of college learning basic theory (*e.g.*, fluid dynamics, heat and mass transfer, thermodynamics). This practice may hinder students' ability to connect their choice of major with their career goals and may reduce student persistence in the field or lead to a loss of motivation and perceived relevance of their chosen field. Additionally, students may be more engaged with the material if the connections to "real-world applications" are made explicit throughout their college studies rather than simply giving a perfunctory nod to the importance of the material for use in activities which may not appear until much later. For example, students may be told that thermodynamics is important because it allows them to predict system properties that will be used later in their design courses and often are expected to simply learn the principles first. However, the lack of a connection in the present course may negatively influence their perception of the material and its usefulness for their future career. Additionally, students may have difficulty applying abstract concepts and ideas to practical applications. Being able to understand the physical meaning of equations and manipulate those equations is an important engineering skill. Many students have difficulty grasping and understanding the abstract concepts of thermodynamics, making it one of the most difficult courses in the undergraduate career.[28,29] Creating connections to real-world scenarios that chemical

Students' experiences in their high school chemistry classrooms tell us how students engaged in chemistry classes may develop a particular connection to the material and see a future in chemical engineering

engineering students will implement in their careers may help students see the importance of the material and grasp concepts before the final year in senior design.

In previous work, engineering majors have been found to have marginally lower socio-economic status, stronger math skills, and less parental and teacher encouragement towards science than science majors.[30] From the current work, it can be seen that chemical engineering students are a demonstrably different group from other engineers. Further investigation of the specific pre-college influences and experiences that cause students to choose chemical engineering over other career choices is a topic for future study. The implications of the current findings, however, are that students' experiences in high school chemistry and a desire for deep understanding of natural phenomena may predict entrance into chemical engineering, and it may be possible to target students for recruitment into chemical engineering through specific support and encouragement. Additionally, a pedagogy that reflects students' deep interest in why things work and the premise behind particular chemical engineering theories may increase student interest in chemical engineering coursework.

CONCLUSIONS

The findings in this work have implications for student recruitment and/or matriculation into chemical engineering and how to improve the relevance and effectiveness of college instruction for these students.

To summarize the results of this paper in a useful way, we have prepared a list of possible considerations that may lend guidance to the recruitment, retention, and effective instruction of chemical engineering students:

- *Given the number of differences in the attitudes of chemical engineering students identified in this study, it may be less than optimal to the retention of these majors to make over-generalizations about "engineering students" when designing curricula or pedagogy in general.*
- *As chemical engineering students have been found to have particularly high expectations towards solving societal problems in their careers including a more frequent desire to address sustainability-related issues (disease, climate change, energy and water supply), it is likely to be beneficial (to their motivation, engagement, and ultimate performance) to regularly address, as part of the normal classroom activities, how and why the content students are learning can be used to address specific social issues.*
- *Similarly, since chemical engineering students have been found to put more weight on developing a deep understanding (of natural phenomena, in everyday life, using scientific questioning and evidence), attention should be paid in the classroom to explaining physical phenomena in more detail and to connecting these topics explicitly to students' everyday lives.*
- *It appears that chemical engineering majors would benefit particularly from having increased opportunities to examine scientific evidence and gain experiences providing explanations/argumentation towards its interpretation. This recommendation is consistent with the broad movement in STEM towards "active" learning environments and the emphasis on inquiry in the classroom; our work indicates that chemical engineering students would respond especially well to increased opportunities for this type of learning.*
- *As we found that chemical engineering students were particularly confident in their abilities to perform tasks related to their scientific and course activities (write a lab report, interpret experimental results, apply knowledge to an assignment/test, get good grades), it may be a waste of time to spend inordinate amounts of class or laboratory time having students develop these meta-cognitive skills; rather, putting more emphasis on other things (as discussed above) may be more beneficial.*
- *Lastly, our results indicate that students who choose chemical engineering are from slightly higher socio-economic backgrounds. In order to increase enrollment and encourage diverse engineering perspectives, less traditional students that may prove to be highly competent engineers should be recruited.*

While chemical engineering students do have clear differences in their career aspirations, understanding of engineering, science identity, chemistry background, and family support than other engineering students, it is important to keep in mind that this group is nonetheless not homogeneous; there are a variety of students that may choose to pursue chemical engineering as a major. Thus, these results should not be over-interpreted to suggest that there is a "one-size-fits-all" solution to the successful recruitment and preparation of the next generation of chemical engineers.

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